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PROCEDURE FOR DETERMINING AERODYNAMIC DRAG AND G PROFILE OF A MISSILE USING UNSMOOTHED POSITION DATA

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STRATEGIC SYSTEMS DEPARTMENT

AUGUST 1982

NAVAL SURFACE WEAPONS CENTER

Dahlgren, Virginia 22448 • Silver Spring, Maryland 20910

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A procedure is described for determining the aerodynamic drag and G profile of a missile using unsmoothed observed position data. The procedure uses numerical integration in computing trajectory data that simulates the observed data. An iterative process is used to obtain a reasonable match between the computed and observed trajectory data. The aerodynamic drag used in computing the trajectory that matches the observed data is a good estimate of the drag of the missile. The G profile is included in the computation. An example is given

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20. ABSTRACT (Cont.)

where the procedure was applied to a B61 Mod 0 bomb deployed in the retarded laydown mode. The results obtained with this procedure are compared to the results obtained using two different smoothing techniques.

FOREWORD

The purpose of this report is to describe a procedure for determining the aerodynamic drag and G profile of a missile. While this procedure has been used to some extent for several decades, it has never been adequately documented.

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This report was reviewed by D. R. Daniel, Head, Exterior Ballistics Branch, and C. W. Duke, Jr., Head, Space and Surface Systems Division.

Released by:

O. F. Braxton

O. F. BRAXTON, Head
Strategic Systems Department

A

CONTENTS

METRIC CONVERSION TABLE

To Convert From	To	Multiply by
inches (in.)	centimeters (cm)	2.54
feet (ft)	meters (m)	0.3048
pounds (lb)	kilograms (kg)	0.45359237

INTRODUCTION

In the decade following World War II, our efforts to develop new missiles and increase our knowledge of exterior ballistics were greatly expanded. Two things that made a large contribution to this effort were the introduction of photo-theodolites to track missiles released from aircraft and electronic computers to analyze the test data.

In the very early stages, the Gâvre drag function was used almost exclusively in a trajectory model to simulate the observed flight data. The drag function was scaled for each store in order to obtain a match between the computed and observed ranges. As the state of the art improved, different drag functions were determined from wind tunnel tests and spark range firings for many of the stores in the Navy stockpile. Refinements were made to these drag functions by comparing observed and computed spatial coordinates at intermediate points in the trajectories as well as the terminal points. Smoothing techniques also became popular for determining the drag function of a missile from observed spatial coordinates since large quantities of test data could be processed quite rapidly with a minimum of labor involved. These smoothing techniques could also be used very effectively, in many instances, to reduce the noise level in the test data. Largely due to their popularity, smoothing techniques have been accepted as the "norm" for establishing aerodynamic coefficients and G schedules using observed position data.

There are a variety of procedures available for determining the aerodynamic drag and G schedule of a missile that involve the use of smoothing techniques. Perhaps the most popular method is a least-squares technique involving the use of a polynomial fit to a moving arc that is evaluated at the midpoint. Another popular method involves digital filters, which may also be applied to trajectory data. Either one of these methods, which involve the use of smoothing techniques, will

provide estimates of velocity and acceleration which are required in computing aerodynamic drag and G schedule. Some of the problems that are encountered with smoothing techniques are described in Appendix A.

While smoothing routines may frequently be used very effectively to reduce the noise in data, they will also reduce large perturbations that may belong in the data. Trajectory data obtained from tracking missiles that have retardation devices activated in flight are extremely difficult to smooth without sacrificing a portion of the peaks that belong in the data.

The procedure described in this report uses a different approach to compute the aerodynamic drag and G schedule of a missile. A particle model is used to compute trajectories that simulate the observed position data. The model uses three translational equations of motion,[1] which provide for motion along three orthogonal axes. The equations are solved using a fourth-order Runga-Kutta method of numerical integration. The rectangular coordinate system, which is illustrated in Figure 1, is described as follows.

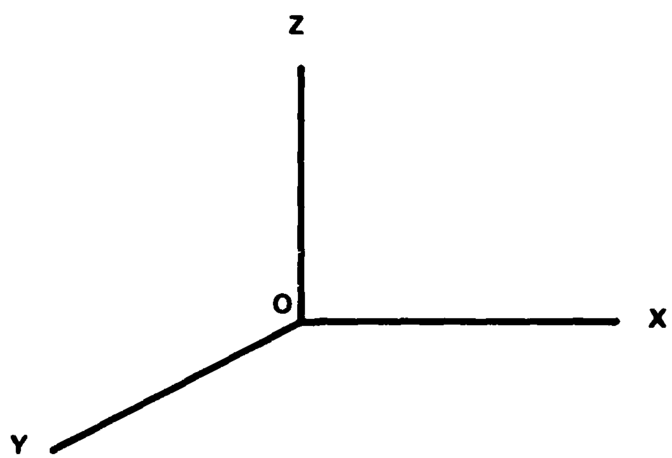

FIGURE 1. RECTANGULAR COORDINATE SYSTEM

The XY plane is perpendicular to the plumb line passing through the range origin, O, and tangent to the mean-sea-level Clarke spheroid of 1866 at the origin. The X axis is positive in the direction of true north, the positive Y axis is 90° clockwise from the positive X axis, and the Z axis is positive upward.

Trajectories are computed with this model, and the results are compared to the unsmoothed position data obtained by tracking the missile in flight. Adjustments are made to the ballistic parameters used in the computation until the differences in computed and observed position data are within the accuracy of the observed data or the differences are not significant. The aerodynamic drag used in computing the trajectory that matches the observed data provides a good estimate of the aerodynamic drag of the missile. The G schedule is included in the computation. To demonstrate the procedure, it was applied to a sample trajectory of the B61 Mod 0 bomb with the parachute deployed in the retarded laydown mode. A comparison of the results obtained with the procedure and two smoothing techniques is presented in the RESULTS section.

PROCEDURE

The method presented in this report for determining the aerodynamic drag and G schedule of a missile using unsmoothed position data may be described in the following manner.

A trajectory is computed with the model outlined in the previous section that simulates the actual conditions of a missile in flight as nearly as possible. A reference weight and diameter of the missile, observed meteorological data, local gravity, and observed event times are used in the computation. The best estimate of initial position, velocity, event times, and aerodynamic drag is used initially. Adjustments to the initial position and velocity are made if necessary to improve the match for a brief period after release. Based on the differences for the remainder of the trajectory, adjustments are made if necessary to the aerodynamic drag and event times. The process is repeated until a match between the observed and computed position data is obtained that is within the accuracy of the observed data or the differences are not significant. The difference between the arc lengths of the observed and computed trajectories are frequently used as a criteria for making final adjustments to the aerodynamic drag. In some situations it may be necessary to concentrate on a segment of a trajectory before attempting to match the next segment or remaining portion.

The procedure was applied to trajectory data for an early version of the B61 Mod 0 bomb deployed in the retarded laydown mode where the parachute failed to open as designed. The trajectory data were provided by Sandia National Laboratories. Meteorological data are tabulated in Appendix B, which were obtained by releasing a radiosonde 4 min prior to the time the store was released.

The actual weight of 715 lb and a reference diameter of 13.5406 in. were used in the computation. A bomb with this diameter has a cross-section area of 1 ft^2; consequently, the CD represents the CDS. The aerodynamic drag of a parachute is stated frequently in terms of CDS. The event times used in the computation were line stretch at 0.75 sec after release and full bloom at 1.60 sec after release. Aircraft position data were used initially to determine the position and velocity at release. Minor adjustments to these values were made in order to improve the match between the observed and computed trajectories during the time from release to the beginning of parachute deployment.

The ground level at the test site is approximately 5330 ft above mean sea level. Cinetheodolites were used to track the aircraft and store to obtain spatial coordinates. Mitchell cameras were used to determine event times.

An aerodynamic drag coefficient as a function of time was used in the computation. After several attempts were made to improve the match between the observed and computed position data, a drag coefficient was obtained that provided an excellent match in trajectory arc length over the entire trajectory. This match in arc length was based on the assumption that the aerodynamic drag force is always parallel and in the opposite direction to the true airspeed of the missile.

There were, however, noticeable differences in range and deflection at intermediate and terminal points that could not be eliminated by adjusting the initial release conditions. The differences suggested the possibility that there were forces normal to the velocity acting on the store. The following paragraph substantiates the possibility.

"The great majority of canopy designs of all types generate unsymmetrical aerodynamic forces, the force vector does not remain steadily tangent to the flight

patch and will create oscillation inducing moments if a stable glide is not possible."[2]

In order to compensate for the differences in range and deflection without affecting the match in arc length, two additional accelerations were included in the equations of motion. These accelerations were perpendicular to the velocity of the store; one was in a vertical plane and the other in a horizontal plane (see Appendix C) and were made proportional to the dynamic air pressure beginning at 1.3 sec after release. Proportionality constants were determined by trial and error that reduced the range and deflection differences at both intermediate and terminal points to values that were considered insignificant without affecting the match in arc length.

The acceleration, G, was computed for every time line by dividing the vector sum of the components of acceleration by the acceleration of gravity.

RESULTS

Graphs of the aerodynamic drag, CD, and G profile obtained with the procedure described in this report are presented in Figures 2 and 3. The same values are also presented in Figures 4 and 5 along with the values obtained by using two different smoothing techniques. In these figures, the curves labeled A were obtained by smoothing the observed position data with a constrained low pass CHI digital filter. The curves labeled B were obtained by fitting a moving arc of 11 data points with a least-squares second-degree polynominal evaluated at the midpoint. The moving arc procedure is described in Reference 3. The curves labeled C in Figures 4 and 5 are the same curves that are shown in Figures 2 and 3 but drawn to different scales.

It may be noted that the aerodynamic drag shown in Figure 2 that was computed using numerical integration contains spikes that do not appear in the drags computed using smoothing techniques. The spikes indicate that the parachute partially collapsed twice before it reached full bloom. This conclusion is supported

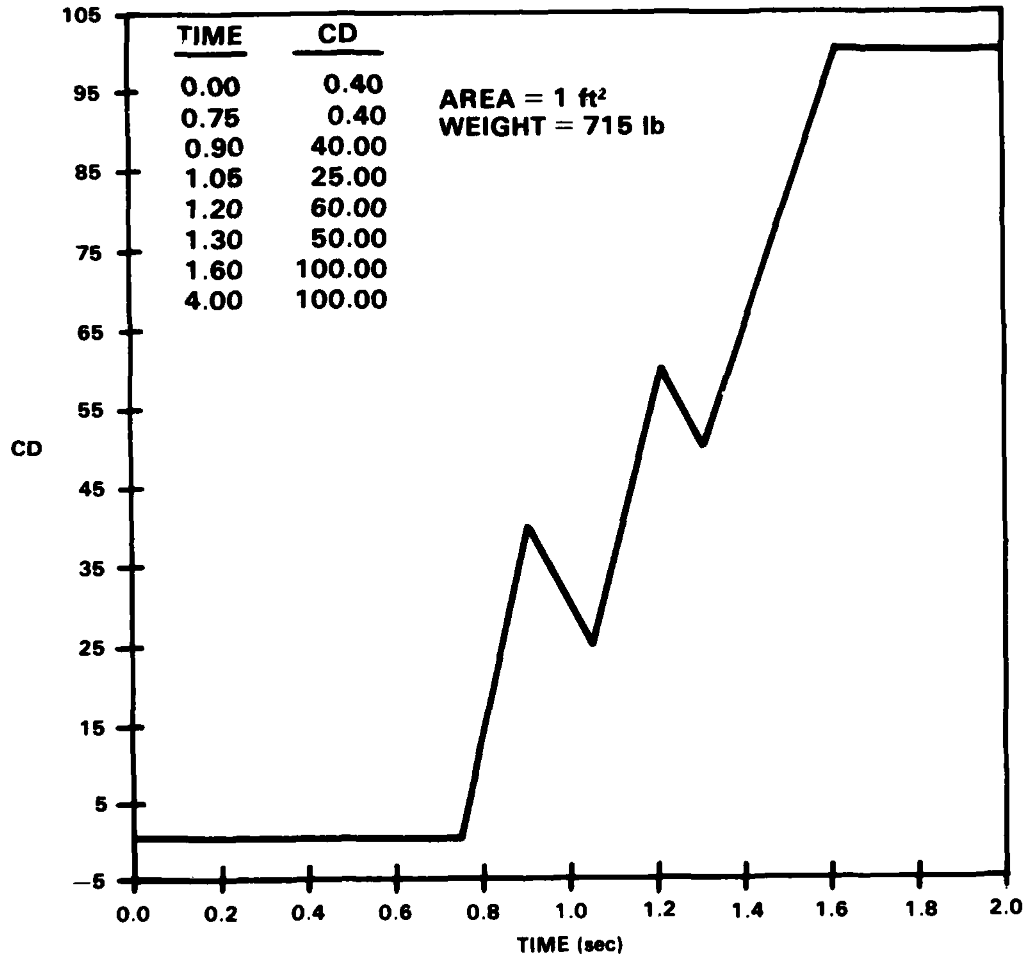

FIGURE 2. DRAG COEFFICIENT VERSUS TIME

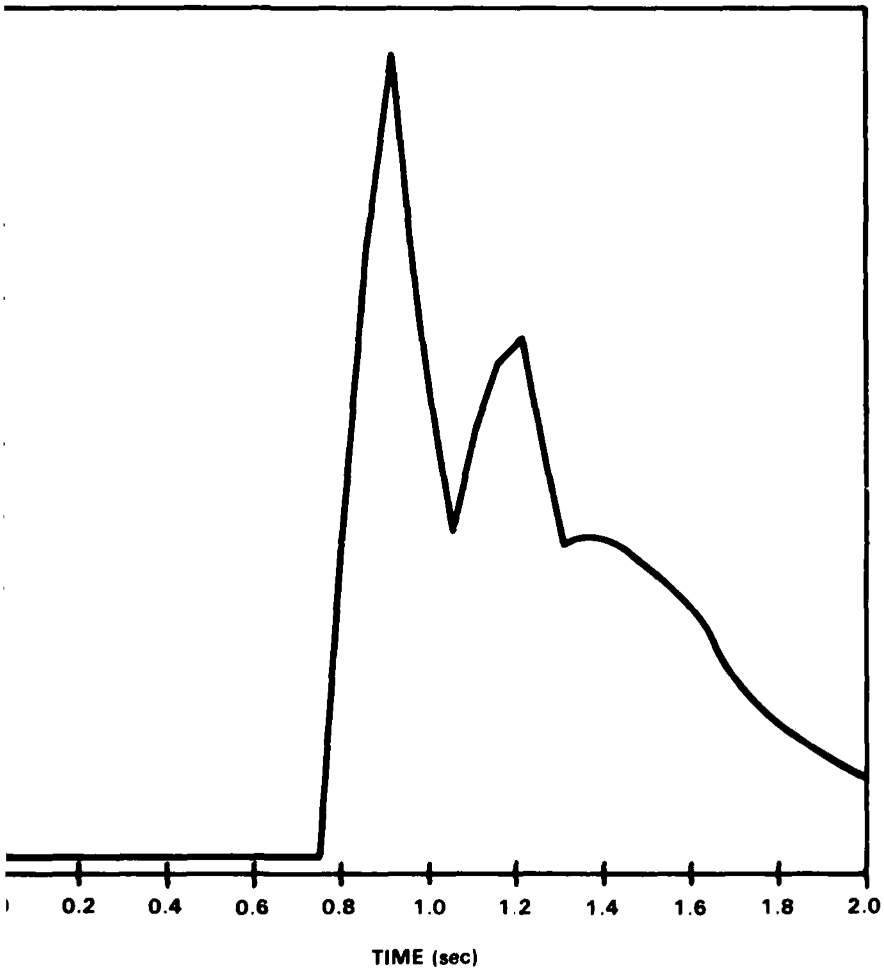

FIGURE 3. G VERSUS TIME

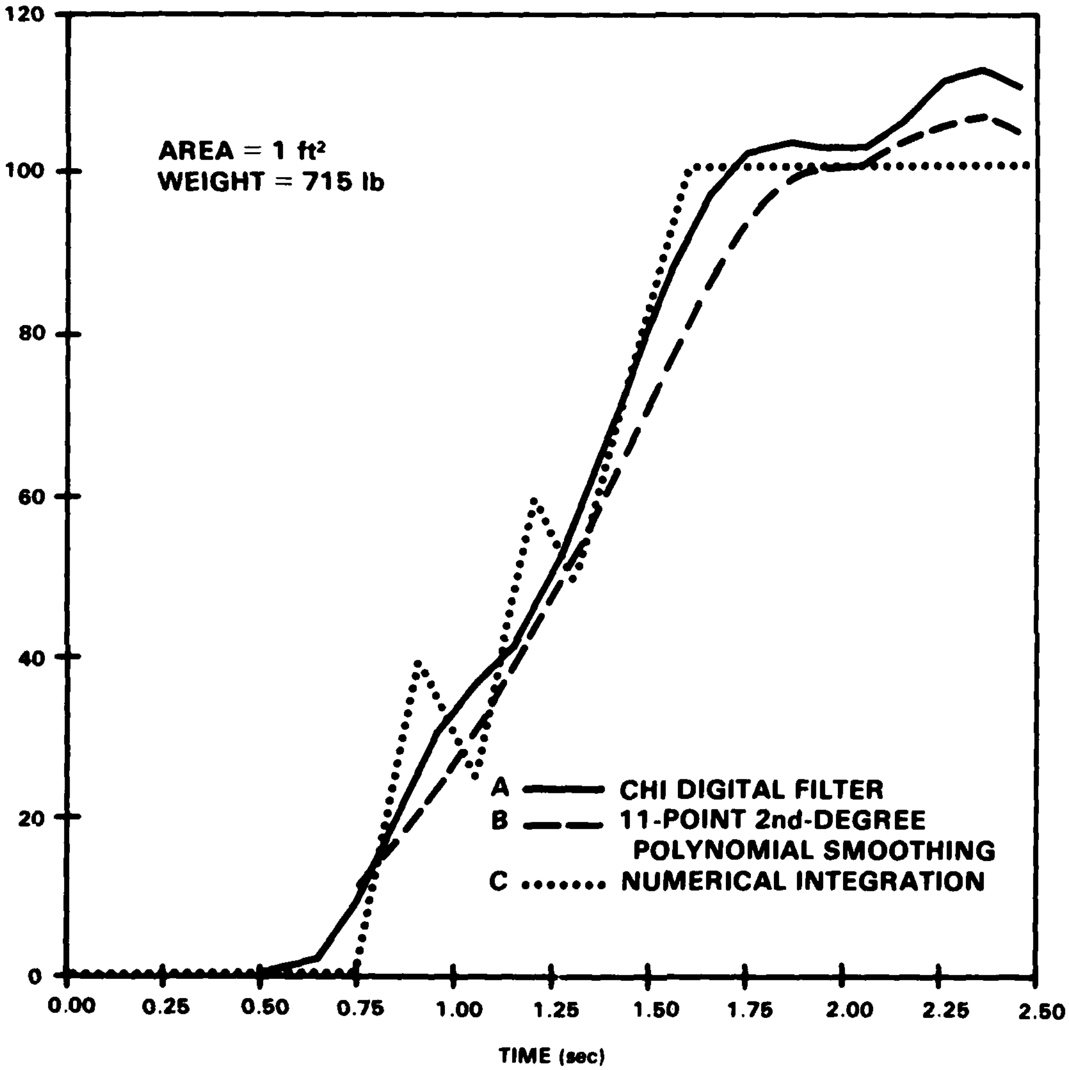

FIGURE 4. DRAG COEFFICIENT VERSUS TIME

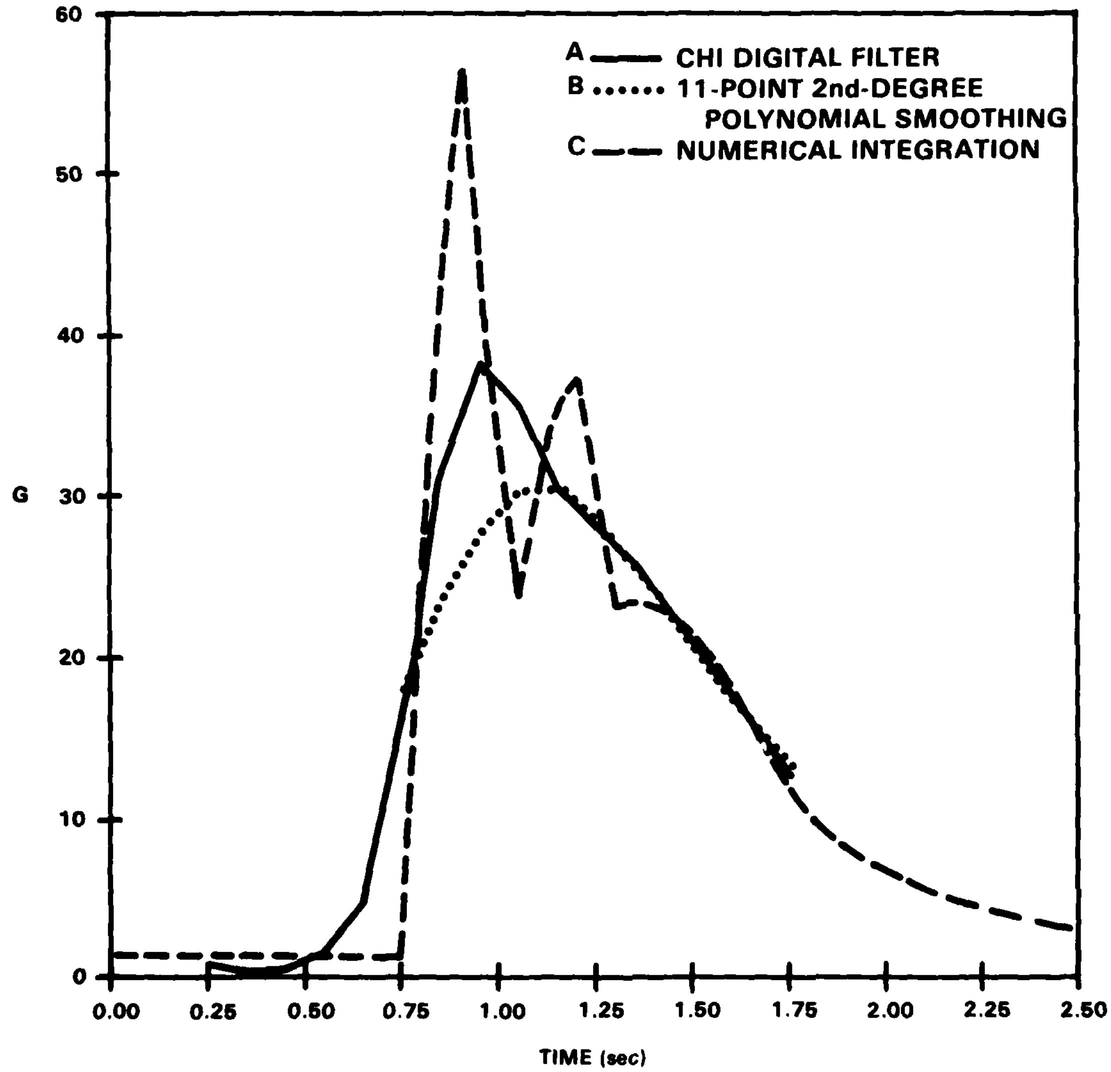

FIGURE 5. G VERSUS TIME

by the fact this parachute took approximately 0.5 sec longer than normal to reach full bloom.

The spikes in the aerodynamic drag are reflected in the G schedule that has a considerably larger maximum G than was obtained by either one of the methods that involves a smoothing technique.

The method of using numerical integration to determine the aerodynamic drag has another distinct advantage when the store is subjected to normal forces. Small forces in this category may be identified and evaluated, which most likely would go undetected, if a smoothing technique were used. The accelerations perpendicular to the velocity used in the sample trajectory shift the terminal point of the trajectory 16 and 36 ft in range and deflection, respectively, and also improve the match between the observed and computed position data at intermediate points. It was possible by using the method presented in this report to obtain an excellent match in all three position coordinates throughout the entire sample trajectory.

Four sets of differences between the computed and observed position data are given in Appendix D for every time line of the computed trajectory. The first set was obtained by comparing the observed position data with a trajectory that was computed using the drag shown in Figure 2 and the accelerations described in Appendix C. The second set is differences obtained by using the same drag but without the accelerations. The third set was obtained by using the drag labeled A in Figure 4. This drag was computed by smoothing the data with a constrained low-pass CHI digital filter. The fourth set was obtained by using the drag labeled B in Figure 4 that was computed by smoothing the data with a second-degree polynomial fit to a moving arc consisting of 11 data points. The differences in time of flight, range, deflection, and arc length at the terminal point and the maximum G are summarized in Table 1.

TABLE 1. DIFFERENCES BETWEEN OBSERVED AND COMPUTED TRAJECTORIES

Set	Time of Flight (sec)	Range (ft)	Deflection (ft)	Arc Length (ft)	Max G
1	-0.025	-2.480	-1.386	1.846	56.6
2	-0.183	-15.986	35.594	1.915	56.6
3	-0.237	-5.403	35.571	13.412	36.8
4	-0.158	-45.001	35.291	-27.865	30.6

The differences are the observed minus the computed values.

The maximum G in Set 3 is 66% of the value in Sets 1 and 2. The maximum G in Set 4 is 56% of the value in Sets 1 and 2. Set 4 has the largest differences in range, deflection, and arc length. A noticeable improvement in the differences throughout the trajectory, as well as the terminal point, was made by introducing the accelerations perpendicular to the velocity vector. There is only one difference in the X, Y, and Z position coordinates in Set 1 in the entire trajectory that exceeds 4 ft and a majority of the differences is less than 2 ft. The differences in arc length are even less. Only four of the differences in arc length exceed 2 ft and the maximum is 2.65 ft.

The unsmoothed position data are presented in Appendix E. The trajectory data computed using the aerodynamic drag shown in Figure 2 and the acceleration described in Appendix C are presented in Appendix F.

This procedure of matching unsmoothed observed position data with computed position data can also be used to identify and correct erroneous observed event times such as parachute deployment schedules, rocket motor ignition and burnout, and booster motor separation, etc. It can also be used to derive rocket-thrust curves, separation effects due to launch disturbances, bomb rack ejection velocity, and a host of other parameters encountered in trajectory analysis. However, this procedure, in some cases, may be laborious and require previous knowledge of certain parameters in order to isolate others. The accuracy of the results obtained are also highly dependent upon the accuracy of the unsmoothed position data. In summary, if the analyst is working with a weapon that has no inflight events or is interested only in a set of parameters that will predict the trajectory impact point, then a procedure that employs smoothing may produce satisfactory results with minimum effort. Conversely, if the weapon is subject to events that produce accelerations and the analyst is interested in accurate estimates of these events, then the use of the trajectory matching technique should be attempted.

CONCLUSIONS

The procedure described in this report makes it possible to determine the aerodynamic drag and G profile of a missile that has large perturbations or very high decelerations occurring in a very short time without smoothing the spatial coordinates.

The accelerations (decelerations) that result from perturbations in a trajectory may be determined with much greater accuracy using numerical integration to match observed position data than can be obtained with any of the existing smoothing techniques.

This procedure may be used to pinpoint phenomena that might otherwise escape identification, if one of the available smoothing techniques were used. Many of the procedures frequently used employ smoothing techniques that reduce the peaks and valleys in the data that may actually belong there. This procedure avoids that problem by using unsmoothed data.

Smoothing techniques may be used to a good advantage to reduce the noise in data where there are no large or abrupt changes in the velocity or acceleration but will invariably reduce any sudden perturbations that may belong in the data.

Recording accelerometers are often used to monitor flight gear and fuze performance during drop tests. The high costs, additional instrumentation requirements, and sometimes low success rate of using recording accelerometers make the method presented in this report an attractive alternate or backup. The procedure provides for the reduction of G data without requiring any modifications or instrumentation of the store.

REFERENCES

1. *PREPARATION OF EXTERIOR BALLISTIC TABLES*, NAVORD Report 5136 First Revision, (Dahlgren, Va., 14 March, 1958).

2. *RECOVERY SYSTEMS DESIGN GUIDE*, Technical Report AFFDL-TR-78-151, Wright-Patterson Air Force Base (Oh., December 1978, p. 271).

3. Barker, R. G., C. H. Frick, and L. J. McAnelly, *A METHOD FOR DETERMINING DRAG COEFFICIENTS FROM OBSERVED POSITION DATA*, NWL Report TR-2291 (Dahlgren, Va., April 1970).

APPENDIX A

SMOOTHING TECHNIQUES

SMOOTHING TECHNIQUES

The decision of selecting an appropriate method for smoothing data may not be an easy task. It is important to select a function that fits the true value of the data. There may be a temptation to increase the degree of a polynomial used in a least-squares fit, in order to reduce the sum of the squares of the residuals. This could be carried to the point where one was merely fitting the noise. Increasing the degree of a polynomial beyond that which fits the true value of the data should be avoided if possible. Unless some information is available about the nature of the data, it may be extremely difficult to determine what function fits the true value when the data contains noise. In the event that this information is available and an appropriate function has been selected, the next decision is the number of data points to be used in the fit. What frequently happens in actual practice is that the function selected for smoothing is only a good approximation of the true value over a short segment of the data. Increasing the length of the segment by using more data points may actually degrade the results. It is desirable to use a function that is a good approximation over a large enough segment of data that the noise level within the fit will have a random distribution. (It is quite possible to encounter noise that does not have a random distribution that further complicates the problem.)

Excellent results can usually be obtained by using a second-degree polynominal to smooth trajectory data that contain moderate levels of acceleration and noise. Smoothing data with high levels of acceleration as in the case of a weapon that has a parachute to increase the air resistance is frequently difficult to perform regardless of the procedure used. The quality of the data may also be an important factor; it may be so poor that no attempt should be made to smooth it. Two excellent sources of information on smoothing techniques are References A-1 and A-2.

There is a diversity of opinion among people who process and analyze data concerning the many numerical methods used in smoothing measured quantities and in the retrieval of information from erroneous observations. The literature on this subject is voluminous. Of the many methods, all use assumptions of the functional form of the basic data trend or statistical properties or origin of errors in an effort to obtain a numerical process which will, within the imposed constraints, improve the data by minimizing errors. The choice of a technique must depend upon the objective sought. Some investigation of a given technique's potential in describing the data must be made.[A-1]

The concept of smoothing is based on the fact that physical events occur at continuously varying rates in nature. In ballistic missiles, while moments of apparent discontinuity in a trajectory do occur during periods of large accelerations (i.e., control changes, thrust initiation or termination, reentry, etc.), the trajectory basically is defined by a continuous function. At this point it should be emphatically stated that <u>smoothing does not improve the accuracy of the observations</u>; it merely presents the most likely performance of the observed phenomena based on the recorded observations. It may deprecate the quality of the data, if it removes actual perturbations in the observed function. There are three currently used techniques of smoothing: use of orthogonal polynomials (applied to trajectory data to get an analytical expression for the actual trajectory), differencing equations, and moving averages. The most commonly used of the three is the moving-average technique.[A-2]

In spite of the fact that the above restrictions on the use of smoothing routines are frequently ignored, fairly good estimates of position, velocity, and acceleration are produced using standard smoothing if the universe of calculated data is sufficiently large.

One final comment should be made regarding the use of standard smoothing routines. Mathematical models employed do not incorporate known external information about the observed phenomena.[A-2]

The above quotation is preceded by a lengthy discussion of a number of restrictions.

REFERENCES

A-1. *ERROR ANALYSIS AND METHODS FOR ESTIMATING ERRORS IN POSITION, VELOCITY AND ACCELERATION DATA*, Document 119-71, published by the Secretariat, Range Commanders Council (White Sands Missile Range, N.M., May 1971, p. 83).

A-2. Ernest H. Ehling, *RANGE INSTRUMENTATION*, (Englewood Cliffs, N.J.: Prentice-Hall, 1976, pp. 559, 563).

APPENDIX B

METEOROLOGICAL DATA

PROGRAM 112488821

DENSITY TABLE IN SEQUENTIAL FILE

7412050120 IDEN 113 JE 2 LAST 50.000 DX

ALTITUDE	TEMP	DENSITY	ALTITUDE	TEMP	DENSITY	ALTITUDE	TEMP	DENSITY	ALTITUDE	TEMP	DENSITY
5000.	277.0389	.06504000	5050.	277.0389	.06504000	5100.	277.0389	.06504000	5150.	277.0389	.06504000
5200.	277.0389	.06504000	5250.	277.0389	.06504000	5300.	277.0389	.06504000	5350.	277.5667	.06486839
5400.	276.7179	.06447293	5450.	276.4093	.06442242	5500.	276.1500	.06436000	5550.	276.1500	.06424000
5600.	276.1500	.06412000									

WIND TABLE IN SEQUENTIAL FILE

7412050120 IDEN 113 JE 2 LAST 50.000 DX

ALTITUDE	N*	E*	ALTITUDE	N*	E*	ALTITUDE	N*	E*	ALTITUDE	N*	E*
5000.	-6.0000	9.7000	5050.	-6.0000	9.7000	5100.	-6.0000	9.7000	5150.	-6.0000	9.7000
5200.	-6.0000	9.7000	5250.	-6.0000	9.7000	5300.	-6.0000	9.7000	5350.	-7.1984	4.6581
5400.	-8.2414	-5.6051	5450.	-9.2515	-2.0697	5500.	-10.1373	1.1000	5550.	-10.3787	2.4000
5600.	-10.6040	3.7000									

APPENDIX C

EQUATIONS FOR ACCELERATIONS PERPENDICULAR TO THE VELOCITY

:ONS FOR ACCELERATIONS PERPENDICULAR TO THE VELOCITY

used to compute the accelerations perpendicular to the velocity

;*Q*GR (ft/sec^2)
:*Q*GR (ft/sec^2)
')/(2.0*GR) (lb/ft^2)
(ft^2/lb)
:ft^2/lb)

leration in the vertical plane and perpendicular to the

leration in the horizontal plane and perpendicular to the

ic air pressure
density (lb/ft^3)
airspeed (ft/sec)
leration of gravity (ft/sec^2)

'Y are positive and the velocity vector has a horizontal direc-
ı acceleration upward and AY produces an acceleration to the
m the rear of the missile.

APPENDIX D

DIFFERENCES BETWEEN UNSMOOTHED AND COMPUTED DATA

SET 1

Set 1 shows the differences between observed position data and data computed using the aerodynamic drag labeled C in Figure 4 and the accelerations perpendicular to the velocity vector as described in Appendix C.

0.000 0.000 0.000 X,Y,Z RADAR

120574 200 6 JUNIT 1 NV 1 NSEQ 1 LAST IDENT IFM
120574 200 SANDIA 301 1

T	XD	YD	ZD	VD	X*	Y*	Z*	VA	MACH NO	ARD
0.000	0.000	0.000	0.000	-1175.000	1147.000	-252.800	-33.300	1184.961	1.08022	0.000
.150	-.900	2.056	-1.628	-1171.373	1143.319	-251.977	-39.011	1181.167	1.07671	-1.254
.300	-1.200	3.190	-2.100	-1167.790	[illegible]	-251.161	-42.707	1177.394	1.07321	-1.771
.450	-.270	3.510	-1.540	-1164.250	[illegible]	-250.350	-47.389	1173.643	1.06972	-.952
.600	-.310	3.600	-.880	-1160.753	1132.415	-249.546	-52.056	1169.913	1.06624	-1.037
.750	-.200	.970	-1.120	-1157.299	1128.826	-248.749	-56.709	1166.205	1.06278	-.335
.750	-.200	.970	-1.120	-1157.299	1128.826	-248.749	-56.709	1166.205	1.06278	-.335
.800	-.780	.330	-1.270	-1136.327	1108.280	-244.281	-57.274	1145.143	1.04356	-.750
.850	-1.440	-.130	-1.230	-1079.702	1052.936	-232.263	-56.002	1088.430	.99185	-1.294
.900	-1.660	-.430	-.990	-997.408	972.540	-214.820	-53.307	1006.051	.91676	-1.455
.950	-.570	-1.030	-.900	-918.698	895.642	-198.149	-50.678	927.256	.84494	-.266
1.000	-.340	-1.450	-.910	-859.844	838.122	-185.689	-49.014	868.314	.79121	.051
1.050	.180	-2.010	-.980	-815.614	794.873	-176.328	-48.080	823.999	.75081	.685
1.100	-.520	-2.420	-1.100	-771.102	751.348	-166.917	-47.039	779.402	.71015	.103
1.150	-.800	-2.550	-.890	-717.077	698.543	-155.511	-45.322	725.295	.66084	-.154
1.200	-1.300	-2.080	-.180	-658.204	641.008	-143.097	-43.176	666.343	.60711	-.780
1.250	-.600	-1.820	-.170	-605.361	589.358	-131.964	-41.290	613.423	.55888	-.153
1.300	-.020	-1.450	-1.140	-563.973	548.882	-123.248	-40.050	571.962	.52109	.417
1.300	-.020	-1.450	-1.140	-563.973	548.882	-123.248	-40.050	571.962	.52109	.417
1.350	1.220	-.000	-1.530	-526.766	513.434	-110.748	-40.036	534.728	.48716	1.394
1.400	2.440	3.240	-1.040	-489.441	477.642	-99.172	-39.689	497.373	.45312	2.108
1.450	3.240	4.530	-.770	-452.989	442.508	-88.643	-39.096	460.392	.41987	2.654
1.500	2.470	3.230	-.830	-418.111	408.749	-79.194	-38.337	425.983	.38806	2.206
1.550	2.140	2.270	-.930	-395.251	376.830	-70.799	-37.478	393.090	.35809	2.077
1.600	1.550	2.120	-1.080	-354.646	347.012	-63.394	-36.571	362.453	.33017	1.565
1.650	1.590	2.230	-1.280	-327.440	320.441	-57.057	-35.767	335.214	.30535	1.598
1.700	1.650	2.940	-1.500	-304.070	297.565	-51.741	-35.160	311.809	.28403	1.587
1.750	1.790	3.420	-1.360	-283.782	277.663	-47.229	-34.714	291.487	.26551	1.625
1.800	1.340	3.680	-.630	-266.009	260.187	-43.360	-34.403	273.679	.24929	1.078
1.850	1.320	3.760	-.320	-250.317	244.719	-40.014	-34.204	257.950	.23495	1.008
1.900	1.410	3.690	-.610	-236.365	230.931	-37.097	-34.102	243.959	.22221	1.180
1.950	1.610	3.280	-.700	-223.881	218.560	-34.537	-34.081	231.437	.21080	1.430
2.000	1.460	2.450	-.500	-212.652	207.399	-32.275	-34.132	220.168	.20053	1.414
2.050	1.250	1.310	-.490	-202.502	197.277	-30.267	-34.244	209.976	.19124	1.444
2.100	.620	-.220	-.770	-193.286	188.055	-28.475	-34.410	200.717	.18281	1.247
2.150	.430	-1.040	-.850	-184.885	179.616	-26.867	-34.623	192.273	.17511	1.234
2.200	.650	-.740	-.610	-177.201	171.865	-25.420	-34.878	184.543	.16807	1.368
2.250	.640	-.900	-.560	-170.149	164.719	-24.111	-35.170	177.469	.16153	1.373
2.300	.070	-1.720	-.790	-163.653	158.107	-22.905	-35.495	170.974	.15573	1.043
2.350	-.180	-2.210	-.810	-157.653	151.969	-21.788	-35.848	164.972	.15027	.891
2.400	-.140	-2.140	-.510	-152.099	146.257	-20.751	-36.228	159.414	.14522	.856
2.450	.190	-1.530	-.390	-146.947	140.926	-19.782	-36.631	[illegible]	.14053	1.091
2.500	.760	-.000	-.540	-142.156	135.938	-18.876	-37.054	149.455	.13617	1.631
2.550	.790	.560	-.480	-137.696	131.261	-18.023	-37.497	144.983	.13210	1.590
2.600	-.170	-.060	-.090	-133.537	126.866	-17.220	-37.957	140.810	.12831	.697
2.650	-.700	-.520	.120	-129.653	122.727	-16.460	-38.431	136.908	.12477	.215

SET 1 (Continued)

2.700	-.740	-.710	.050	-126.020	118.822	-15.739	-38.920	133.257	.12145	.226
2.750	-.790	-.940	.010	-122.619	115.130	-15.052	-39.421	129.836	.11834	.225
2.800	-.960	-1.210	-.010	-119.433	111.634	-14.397	-39.934	126.626	.11542	.112
2.850	-.960	-1.500	-.000	-116.444	108.318	-13.771	-40.456	123.612	.11269	.150
2.900	-.790	-1.830	.040	-113.638	105.167	-13.169	-40.988	120.779	.11011	.341
2.950	-.980	-2.190	.100	-111.003	102.170	-12.521	-41.527	118.115	.10769	.249
3.000	-1.410	-2.570	.190	-108.528	99.314	-12.033	-42.074	115.608	.10542	-.158
3.050	-1.410	-2.580	.310	-106.201	96.589	-11.494	-42.627	113.248	.10327	-.213
3.100	-.670	-2.020	.450	-104.012	93.985	-10.972	-43.186	111.025	.10126	.391
3.150	-.410	-1.280	.430	-101.955	91.494	-10.465	-43.750	108.930	.09935	.611
3.200	-.920	-.270	.130	-100.019	89.108	-9.972	-44.318	106.955	.09756	.310
3.250	-.920	.510	-.140	-98.128	86.820	-9.491	-44.889	105.093	.09587	.424
3.300	-.210	.980	-.380	-96.485	84.623	-9.022	-45.464	103.338	.09428	1.142
3.350	.210	.810	-.600	-94.875	82.512	-8.562	-46.041	101.684	.09278	1.631
3.400	.140	-.270	-.780	-93.361	80.481	-8.112	-46.619	100.124	.09137	1.877
3.450	-.040	-.570	-.930	-91.938	78.524	-7.669	-47.199	98.655	.09003	1.840
3.500	-.410	.300	-1.060	-90.603	76.639	-7.237	-47.780	97.263	.08877	1.617
3.550	-.900	-.050	-.960	-89.349	74.819	-6.816	-48.362	95.950	.08757	1.200
3.600	-1.600	-2.220	-.520	-88.172	73.060	-6.407	-48.943	94.713	.08645	1.144
3.650	-1.810	-3.010	-.460	-87.070	71.361	-6.009	-49.525	93.548	.08539	1.069
3.700	-1.330	-1.720	-.970	-86.037	69.716	-5.620	-50.105	92.451	.08439	1.846

-.025 DT   -2.720 DX   -.820 DY   -2.480 DR   -1.386 DD   347.5707 AZD

IDENTIFICATION	DT	DR	DD	ARD
1205740200	-.025	-2.480	-1.386	1.846
MEAN	-.025	-2.480	-1.386	1.846
SIGMA	0.000	0.000	0.000	0.000

COMMAND-

Note: The observed velocity of the bomb was input as zero; consequently, the difference in velocity, VD, has the same magnitude as the computed velocity but opposite in sign.

SET 2

Set 2 shows the differences between observed position data and data computed using the aerodynamic drag labeled C in Figure 4 and without the accelerations perpendicular to the velocity vector as described in Appendix C.

0.000 0.000 0.000 X,Y,Z RADAR

128574 200 6 JUNIT 1 NV 1 NSEQ 1 LAST IDENT IFN
128574 200 SANDIA 861 1

T	XD	YD	ZD	VD	X*	Y*	Z*	VA	MACH NO	ARD
0.000	0.000	0.000	0.000	-1175.000	1147.000	-252.000	-33.300	1184.961	1.08022	0.000
.150	-.900	2.056	-1.620	-1171.373	1143.319	-251.977	-38.011	1181.167	1.07671	-1.254
.300	-1.200	3.190	-2.100	-1167.790	1139.661	-251.161	-42.707	1177.394	1.07321	-1.771
.450	-.270	3.510	-1.540	-1164.250	1136.027	-250.350	-47.389	1173.643	1.06972	-.952
.600	-.310	3.600	-.800	-1160.753	1132.415	-249.546	-52.056	1169.913	1.06624	-1.037
.750	-.200	.970	-1.120	-1157.299	1128.926	-248.749	-56.709	1166.205	1.06278	-.335
.750	-.200	.970	-1.120	-1157.299	1128.826	-248.749	-56.709	1166.205	1.06278	-.335
.800	-.780	.330	-1.270	-1136.327	1108.280	-244.281	-57.274	1145.143	1.04356	-.756
.850	-1.440	-.130	-1.230	-1079.702	1052.936	-232.263	-56.002	1088.430	.99185	-1.294
.900	-1.660	-.430	-.990	-997.408	972.540	-214.020	-53.307	1006.051	.91676	-1.455
.950	-.570	-1.030	-.900	-918.698	895.642	-198.149	-50.678	927.256	.84494	-.266
1.000	-.340	-1.450	-.910	-859.844	838.122	-185.689	-49.014	868.314	.79121	.051
1.050	.180	-2.010	-.580	-815.614	794.873	-176.328	-48.080	823.999	.75081	.685
1.100	-.520	-2.420	-1.130	-771.102	751.348	-166.917	-47.039	779.402	.71015	.163
1.150	-.800	-2.550	-.890	-717.077	698.543	-155.511	-45.322	725.295	.66084	-.154
1.200	-1.300	-2.080	-.180	-658.204	641.008	-143.097	-43.176	666.343	.60711	-.780
1.250	-.600	-1.820	-.170	-605.361	589.358	-131.964	-41.290	613.423	.55888	-.153
1.300	-.020	-1.450	-1.140	-563.973	548.882	-123.248	-40.050	571.962	.52109	.417
1.300	-.020	-1.450	-1.140	-563.973	548.882	-123.248	-40.050	571.962	.52109	.417
1.350	1.240	.120	-1.560	-526.767	512.486	-115.426	-38.990	534.685	.48712	1.396
1.400	2.530	3.690	-1.140	-499.446	475.978	-107.578	-37.818	497.293	.45305	2.107
1.450	3.430	5.480	-.980	-453.003	440.327	-99.528	-36.576	460.781	.41977	2.655
1.500	2.780	4.790	-1.180	-418.134	406.213	-92.619	-35.343	425.846	.38794	2.269
1.550	2.580	4.550	-1.440	-385.285	374.068	-85.740	-34.149	392.933	.35795	2.094
1.600	2.130	5.190	-1.760	-354.694	344.125	-79.342	-33.021	362.275	.33001	1.557
1.650	2.310	6.100	-2.140	-327.501	317.494	-73.659	-32.075	335.019	.30518	1.592
1.700	2.520	7.650	-2.550	-304.142	294.547	-68.781	-31.374	311.597	.28384	1.571
1.750	2.800	8.990	-2.600	-283.864	274.699	-64.549	-30.869	291.257	.26531	1.666
1.800	2.510	10.120	-2.060	-266.100	257.246	-60.843	-30.525	273.432	.24907	1.357
1.850	2.640	11.080	-1.940	-250.415	241.815	-57.572	-30.313	257.685	.23472	.985
1.900	2.900	11.880	-2.430	-236.468	228.071	-54.664	-30.212	243.675	.22195	1.156
1.950	3.210	12.350	-2.720	-223.991	215.752	-52.063	-30.204	231.135	.21053	1.393
2.000	3.210	12.390	-2.710	-212.766	204.647	-49.724	-30.275	219.846	.20024	1.382
2.050	3.130	12.120	-2.890	-202.610	194.583	-47.608	-30.414	209.634	.19094	1.400
2.100	2.630	11.460	-3.370	-193.405	185.421	-45.687	-30.612	200.355	.18248	1.194
2.150	2.570	11.500	-3.670	-185.006	177.044	-43.934	-30.861	191.890	.17477	1.174
2.200	2.920	12.650	-3.540	-177.323	169.355	-42.336	-31.154	184.138	.16771	1.365
2.250	3.030	13.330	-3.710	-170.272	162.271	-40.856	-31.487	177.017	.16122	1.299
2.300	2.580	13.340	-4.130	-163.782	155.723	-39.498	-31.854	170.455	.15524	.964
2.350	2.450	13.580	-4.330	-157.791	149.651	-38.240	-32.251	164.444	.14977	.867
2.400	2.610	14.560	-4.290	-152.241	144.001	-37.058	-32.675	158.911	.14474	.771
2.450	3.040	15.990	-4.260	-147.090	138.731	-35.943	-33.123	153.775	.14007	.986
2.500	3.730	18.260	-4.590	-142.297	133.802	-34.888	-33.591	149.000	.13573	1.533
2.550	3.860	19.680	-4.700	-137.831	129.181	-33.888	-34.078	144.551	.13169	1.478
2.600	3.810	19.850	-4.490	-133.662	124.839	-32.937	-34.581	140.399	.12791	.586
2.650	2.570	20.170	-4.440	-129.765	120.752	-32.030	-35.099	136.520	.12439	.696

SET 2 (Continued)

2.700	2.630	20.750	-4.670	-126.117	116.097	-31.163	-35.631	132.090	.12109	.057
2.750	2.600	21.290	-4.800	-122.700	113.234	-30.333	-36.175	129.490	.11800	.097
2.800	2.600	21.790	-5.060	-119.492	109.804	-29.536	-36.729	126.301	.11516	-.024
2.850	2.690	22.240	-5.210	-116.400	106.533	-28.769	-37.292	123.309	.11239	.015
2.900	2.940	22.660	-5.330	-113.651	103.427	-28.030	-37.864	120.497	.10983	.150
2.950	2.950	23.050	-5.420	-110.989	100.471	-27.316	-38.444	117.855	.10743	.155
3.000	2.490	23.400	-5.480	-108.485	97.656	-26.625	-39.030	115.369	.10517	-.314
3.050	2.580	24.110	-5.520	-106.126	94.970	-25.955	-39.621	113.030	.10305	-.345
3.100	3.390	25.390	-5.520	-103.906	92.405	-25.305	-40.218	110.829	.10105	.251
3.150	3.740	26.840	-5.690	-101.814	89.951	-24.672	-40.818	108.756	.09917	.409
3.200	3.300	28.560	-6.140	-99.843	87.602	-24.056	-41.422	106.803	.09740	.192
3.250	3.370	30.050	-6.550	-97.985	85.349	-23.455	-42.029	104.964	.09573	.309
3.300	4.160	31.210	-6.940	-96.234	83.187	-22.867	-42.639	103.232	.09416	1.049
3.350	4.650	31.730	-7.290	-94.583	81.109	-22.291	-43.249	101.601	.09268	1.547
3.400	4.650	31.330	-7.610	-93.029	79.110	-21.727	-43.862	100.064	.09128	1.016
3.450	4.540	31.710	-7.900	-91.564	77.186	-21.174	-44.474	98.618	.08997	1.793
3.500	4.230	33.250	-8.160	-90.184	75.331	-20.630	-45.087	97.257	.08874	1.503
3.550	3.810	33.570	-8.190	-88.886	73.542	-20.095	-45.700	95.976	.08758	1.196
3.600	3.170	32.860	-7.890	-87.664	71.814	-19.567	-46.312	94.772	.08649	1.159
3.650	3.030	31.930	-7.960	-86.516	70.145	-19.049	-46.923	93.605	.08543	1.116
3.700	3.560	33.070	-8.600	-85.438	68.530	-18.543	-47.533	92.500	.08442	1.915
-.183 DT	-7.950 DX	30.200 DY	-15.986 DR	35.594 DD	347.5707 AZD					

IDENTIFICATION	DT	DR	DD	ARD
1285740200	-.183	-15.986	35.594	1.915
MEAN	-.183	-15.986	35.594	1.915
SIGMA	0.000	0.000	0.000	0.000

Note: The observed velocity of the bomb was input as zero; consequently, the difference in velocity, VD, has the same magnitude as the computed velocity but opposite in sign.

SET 3

Set 3 shows the differences between observed position data and data computed using the aerodynamic drag (labeled A in Figure 4) obtained by smoothing the data with a constrained low-pass CHI digital filter and without the accelerations perpendicular to the velocity vector as described in Appendix C.

0.000 0.000 0.000 X,Y,Z RADAR

120574 200 6 JUNIT 1 NV 1 NSFO 1 LAST IDENT IFM
120574 200 SANDIA PA1 1

T	XD	YD	ZD	VD	X*	Y*	Z*	VR	MACH NO	ARD
0.000	0.000	0.000	0.000	-1175.000	1147.000	-252.600	-33.300	1184.961	1.08022	0.000
.150	-.830	2.036	-1.628	-1170.426	1142.394	-251.775	-37.982	1180.220	1.07584	-1.182
.300	-.920	3.130	-2.110	-1166.226	1138.144	-250.829	-42.658	1175.840	1.07179	-1.484
.450	.110	3.420	-1.550	-1164.295	1136.071	-250.359	-47.401	1173.688	1.06976	-.561
.600	.130	3.500	-.990	-1158.700	1130.411	-249.109	-51.977	1167.861	1.06437	-.586
.750	2.260	.440	-1.230	-1120.163	1092.578	-240.865	-54.971	1129.072	1.02895	2.184
.750	2.260	.440	-1.230	-1120.163	1092.578	-240.865	-54.971	1129.072	1.02895	2.186
.800	3.890	-.690	-1.480	-1086.582	1059.729	-233.724	-54.914	1095.405	.99824	4.035
.850	5.480	-1.640	-1.550	-1040.770	1014.934	-223.597	-54.186	1049.507	.95639	5.786
.900	6.540	-2.220	-1.370	-986.170	961.574	-212.418	-52.928	994.833	.90654	6.947
.950	7.620	-2.810	-1.260	-926.336	903.090	-199.739	-51.297	934.907	.85191	8.123
1.000	7.420	-3.140	-1.240	-866.857	844.961	-187.147	-49.584	875.339	.79761	7.599
1.050	7.893	-3.649	-1.300	-809.572	788.973	-175.030	-47.889	817.969	.74531	8.582
1.100	7.760	-4.220	-1.450	-758.406	737.004	-163.794	-46.325	764.717	.69677	8.503
1.150	8.120	-4.500	-1.270	-707.263	688.962	-153.416	-44.897	715.493	.65191	8.984
1.200	7.830	-4.080	-.560	-660.156	642.907	-143.478	-43.488	668.308	.60890	8.573
1.250	8.190	-3.740	-.520	-615.080	598.833	-133.978	-42.100	623.155	.56775	8.850
1.300	8.329	-3.270	-1.450	-571.691	556.406	-124.843	-40.712	579.692	.52814	8.957
1.300	8.320	-3.270	-1.450	-571.651	556.406	-124.843	-40.712	579.692	.52814	8.957
1.350	9.320	-1.650	-1.850	-530.322	515.950	-116.142	-39.347	538.250	.49037	9.665
1.400	10.490	1.950	-1.420	-490.941	477.434	-107.868	-38.007	498.798	.45442	10.258
1.450	11.340	3.750	-1.250	-453.842	441.144	-100.082	-36.717	461.630	.42055	10.754
1.500	10.640	3.070	-1.440	-419.244	407.294	-92.829	-35.500	426.965	.38896	10.297
1.550	10.370	2.840	-1.700	-387.255	375.987	-86.130	-34.375	394.909	.35975	10.072
1.600	9.790	3.490	-2.000	-358.120	347.463	-80.035	-33.373	365.710	.33314	9.402
1.650	9.780	4.450	-2.360	-331.710	321.594	-74.515	-32.497	339.235	.30902	9.241
1.700	9.790	6.050	-2.750	-308.134	298.486	-69.553	-31.774	315.597	.28748	9.013
1.750	9.890	7.420	-2.780	-287.100	277.852	-65.204	-31.192	294.500	.26826	9.066
1.800	9.460	8.580	-2.230	-268.524	259.610	-61.331	-30.761	275.862	.25128	8.173
1.850	9.490	9.560	-2.100	-252.072	243.433	-57.902	-30.464	259.348	.23623	7.999
1.900	9.690	10.380	-2.580	-237.536	229.117	-54.874	-30.295	244.750	.22293	8.100
1.950	9.950	10.850	-2.870	-224.629	216.381	-52.185	-30.235	231.779	.21111	8.295
2.000	9.930	10.900	-2.850	-213.087	204.968	-49.780	-30.266	220.173	.20054	8.261
2.050	9.840	10.630	-3.040	-202.696	194.669	-47.615	-30.374	209.718	.19101	8.271
2.100	9.350	9.960	-3.520	-193.181	185.215	-45.633	-30.529	200.137	.18228	8.077
2.150	9.310	10.000	-3.790	-184.408	176.476	-43.805	-30.721	191.297	.17423	8.077
2.200	9.690	11.150	-3.740	-176.219	168.297	-42.098	-30.933	183.040	.16671	8.237
2.250	9.870	11.810	-3.890	-168.558	160.625	-40.502	-31.161	175.309	.15966	8.307
2.300	9.520	11.800	-4.330	-161.460	153.491	-39.022	-31.418	168.139	.15313	8.075
2.350	9.510	12.120	-4.550	-154.894	146.865	-37.651	-31.705	161.540	.14712	8.041
2.400	9.820	12.970	-4.460	-148.902	140.790	-36.382	-32.038	155.563	.14169	8.162
2.450	10.420	14.360	-4.550	-143.439	135.220	-35.206	-32.417	150.113	.13673	8.555
2.500	11.290	16.590	-4.510	-138.446	130.098	-34.112	-32.837	145.136	.13221	9.288
2.550	11.610	17.570	-5.060	-133.877	125.377	-33.092	-33.295	140.581	.12807	9.431
2.600	10.950	18.100	-4.880	-129.711	121.036	-32.143	-33.793	136.431	.12430	8.736
2.650	10.700	18.380	-4.680	-125.920	117.048	-31.259	-34.330	132.655	.12087	8.438
2.700	10.540	18.930	-5.150	-122.556	113.457	-30.453	-34.929	129.307	.11782	8.630
2.750	11.150	19.430	-5.390	-119.583	110.730	-29.718	-35.586	126.351	.11514	8.797

SET 3 (Continued)

2.800	11.210	19.900	-5.550	-116.876	107.249	-29.029	-36.273	123.660	.11240	8.819
2.850	11.420	20.330	-5.760	-114.376	104.449	-28.974	-36.979	121.178	.11044	8.979
2.900	11.760	20.740	-5.890	-111.909	101.675	-27.714	-37.651	118.779	.10822	9.249
2.950	11.650	21.100	-5.550	-109.454	98.908	-27.046	-38.288	116.252	.10600	9.290
3.000	11.470	21.440	-6.060	-107.059	96.227	-26.389	-38.912	113.955	.10388	8.898
3.050	11.830	22.140	-6.100	-104.867	93.654	-25.747	-39.536	111.741	.10187	8.933
3.100	12.520	23.420	-6.110	-102.875	91.293	-25.149	-40.203	109.767	.10008	9.586
3.150	12.850	24.660	-6.280	-101.100	89.123	-24.589	-40.911	108.011	.09849	9.862
3.200	12.493	26.570	-6.720	-99.256	86.885	-24.002	-41.552	106.185	.09683	9.599
3.250	12.610	28.060	-7.130	-97.772	84.519	-23.370	-42.097	104.720	.09509	9.759
3.300	13.450	29.210	-7.510	-94.883	81.794	-22.628	-42.433	101.849	.09289	10.540
3.350	14.030	29.720	-7.850	-92.129	78.749	-21.785	-42.564	99.110	.09040	11.132
3.400	14.170	29.290	-8.260	-89.378	75.711	-20.927	-42.642	96.374	.08792	11.945
3.450	14.260	29.610	-8.630	-86.782	72.765	-20.084	-42.718	93.759	.08554	11.749
3.500	14.180	31.100	-8.580	-84.707	70.359	-19.372	-43.008	91.725	.08369	11.788
3.550	14.029	31.350	-9.120	-83.207	69.394	-18.784	-43.506	90.233	.08234	11.682
3.600	13.850	29.780	-8.940	-81.489	66.247	-18.127	-43.855	88.924	.08078	11.950
3.650	13.800	29.560	-9.140	-79.459	63.843	-17.377	-43.999	86.405	.07893	12.239
3.700	14.870	31.410	-9.946	-77.318	61.349	-16.589	-44.032	84.301	.07694	13.412
-.237 DT	2.380 DX	35.960 DY	-5.403 DR	35.571 DD	347.5707 AZD					

IDENTIFICATION	DT	DR	DD	ARD
1209746200	-.237	-5.403	35.571	13.412
MEAN	-.237	-5.403	35.571	13.412
SIGMA	0.000	0.000	0.000	0.000

Note: The observed velocity of the bomb was input as zero; consequently, the difference in velocity, VD, has the same magnitude as the computed velocity but opposite in sign.

SET 4

Set 4 shows the differences between observed position data and data computed using the aerodynamic drag (labeled B in Figure 4) obtained by smoothing the data with a second-degree polynomial fit to a 11-point moving arc evaluated at the midpoint.

0.000 0.000 0.000 X,Y,Z RADAR

120574 200 6 JUNIT 1 NV 1 NSEQ 1 LAST IDENT IFN
120574 200 SANDIA 861 1

T	XD	YD	ZD	VD	X*	Y*	Z*	VA	MACH NO	ARO
0.000	0.000	0.000	0.090	-1175.000	1147.003	-252.000	-33.300	1184.961	1.68022	0.000
.150	-.030	2.036	-1.620	-1170.426	1142.394	-251.775	-37.982	1180.220	1.67504	-1.102
.300	-.920	3.130	-2.110	-1166.236	1138.144	-250.829	-42.650	1175.040	1.67179	-1.404
.450	.110	3.420	-1.550	-1164.295	1136.871	-250.359	-47.401	1173.600	1.66976	-.561
.600	.130	3.500	-.090	-1150.700	1130.411	-249.109	-51.977	1167.061	1.66437	-.506
.750	2.900	.300	-1.260	-1100.714	1081.403	-238.435	-54.431	1117.624	1.01051	2.040
.750	2.900	.300	-1.260	-1100.714	1301.403	-238.435	-54.431	1117.624	1.01051	2.040
.800	5.150	-.960	-1.540	-1074.896	1047.530	-231.074	-54.324	1082.921	.98686	5.325
.850	7.220	-2.810	-1.630	-1034.820	1009.134	-222.733	-53.920	1043.569	.95098	7.577
.900	8.310	-2.600	-1.450	-991.347	966.617	-213.506	-53.250	1000.004	.91125	8.759
.950	8.010	-3.070	-1.310	-944.789	921.097	-203.636	-52.335	953.363	.86873	9.342
1.000	7.440	-3.150	-1.220	-895.696	873.103	-193.239	-51.201	904.170	.82389	8.020
1.050	6.320	-3.350	-1.190	-845.273	823.811	-182.571	-49.902	853.666	.77784	6.972
1.100	4.370	-3.490	-1.230	-794.362	774.043	-171.818	-48.479	802.660	.73135	5.189
1.150	2.900	-3.370	-.950	-743.980	724.791	-161.171	-46.506	752.200	.68535	3.634
1.200	.070	-2.570	-.140	-694.753	676.667	-150.787	-45.459	702.091	.64041	1.440
1.250	-.390	-1.800	-.080	-647.351	630.324	-140.797	-43.938	655.409	.59713	.056
1.300	-1.800	-1.800	-.040	-602.186	586.165	-131.289	-42.454	610.167	.55598	-1.414
1.300	-1.800	-1.800	-.040	-602.186	586.165	-131.289	-42.454	610.167	.55598	-1.414
1.350	-2.250	.850	-1.150	-559.576	544.498	-122.327	-41.032	567.402	.51700	-2.192
1.400	-2.490	4.760	-.640	-519.589	505.390	-113.926	-39.682	527.421	.48049	-3.044
1.450	-3.840	6.060	-.390	-482.299	468.913	-106.099	-38.416	490.059	.44644	-3.982
1.500	-5.120	6.400	-.490	-447.596	434.959	-98.823	-37.235	455.206	.41476	-5.894
1.550	-6.770	6.550	-.660	-415.450	403.4[illegible]9	-92.090	-36.144	423.071	.38540	-7.494
1.600	-8.710	7.490	-.800	-385.810	374.496	-85.891	-35.151	393.372	.35834	-9.555
1.650	-10.060	8.750	-1.140	-358.684	347.837	-80.283	-34.256	366.092	.33340	-11.093
1.700	-11.340	10.620	-1.450	-333.059	323.598	-75.036	-33.478	341.282	.31080	-12.640
1.750	-12.460	12.260	-1.390	-311.395	301.564	-70.356	-32.812	318.753	.29035	-14.040
1.800	-14.030	13.670	-.770	-291.156	281.704	-66.132	-32.266	298.449	.27185	-15.900
1.850	-15.060	14.080	-.570	-272.912	263.705	-62.333	-31.831	280.142	.25517	-17.159
1.900	-15.840	15.910	-.980	-256.619	247.762	-58.942	-31.517	263.785	.24027	-18.661
1.950	-16.460	16.500	-1.210	-242.030	233.401	-55.989	-31.313	249.139	.22692	-18.769
2.000	-17.310	16.800	-1.150	-229.008	220.545	-53.199	-31.213	236.044	.21499	-19.647
2.050	-18.140	16.700	-1.290	-217.333	208.974	-50.765	-31.201	224.275	.20427	-20.396
2.100	-19.320	16.100	-1.730	-206.599	198.370	-48.540	-31.247	213.504	.19445	-21.293
2.150	-19.990	16.360	-1.960	-196.756	188.590	-46.494	-31.330	203.594	.18543	-21.937
2.200	-20.190	17.643	-1.890	-187.743	179.626	-44.621	-31.481	194.513	.17715	-22.366
2.250	-20.560	18.420	-2.010	-179.475	171.371	-42.981	-31.669	186.175	.16956	-22.856
2.300	-21.440	18.530	-2.430	-171.846	163.724	-41.369	-31.893	178.528	.16260	-23.625
2.350	-21.950	18.960	-2.630	-164.774	156.625	-39.810	-32.150	171.479	.15619	-24.164
2.400	-22.110	19.910	-2.510	-158.345	150.1[illegible]9	-38.442	-32.460	165.060	.15036	-24.519
2.450	-21.970	21.403	-2.580	-152.494	144.207	-37.171	-32.820	159.236	.14506	-24.590
2.500	-21.540	23.730	-2.930	-147.081	138.693	-35.976	-33.210	153.842	.14015	-24.299
2.550	-21.640	25.200	-3.060	-142.050	133.549	-34.849	-33.625	148.837	.13560	-24.577
2.600	-22.700	25.420	-2.060	-137.473	128.821	-33.801	-34.082	144.272	.13145	-25.674
2.650	-23.330	25.799	-2.850	-133.294	124.475	-32.827	-34.580	140.112	.12767	-26.345
2.700	-23.450	26.460	-3.110	-129.446	120.438	-31.916	-35.109	136.204	.12419	-26.512
2.750	-23.580	26.970	-3.340	-125.893	116.677	-31.645	-35.663	132.752	.12090	-26.600

SET 4 (Continued)

2.800	-23.830	27.510	-3.540	-122.661	113.212	-33.237	-36.256	129.540	.11066	-26.962
2.850	-23.910	28.093	-3.710	-119.734	110.320	-29.405	-36.800	126.633	.11542	-27.603
2.900	-23.830	28.450	-3.850	-117.144	107.152	-28.796	-37.575	124.464	.11349	-27.057
2.950	-24.030	28.880	-3.550	-114.858	104.553	-28.163	-38.314	121.800	.11103	-27.297
3.000	-24.690	29.270	-4.020	-112.692	102.057	-27.547	-39.051	119.657	.10949	-27.954
3.050	-24.830	30.030	-4.050	-110.591	99.615	-26.935	-39.771	117.570	.10720	-28.207
3.100	-24.250	31.360	-4.540	-108.369	97.057	-26.204	-40.410	115.379	.10521	-27.034
3.150	-24.140	32.060	-4.210	-106.026	94.385	-25.592	-40.964	113.058	.10310	-27.021
3.200	-24.790	34.620	-4.650	-103.746	91.766	-24.983	-41.498	110.801	.10105	-28.317
3.250	-24.920	36.150	-5.060	-101.565	89.233	-24.226	-42.025	108.642	.09909	-28.306
3.300	-24.320	37.350	-5.440	-99.507	86.806	-23.565	-42.557	106.606	.09724	-27.025
3.350	-24.000	37.919	-5.800	-97.571	84.404	-22.921	-43.095	104.691	.09550	-27.479
3.400	-24.170	37.540	-6.130	-95.749	82.259	-22.294	-43.639	102.090	.09387	-27.364
3.450	-24.420	37.940	-6.440	-94.034	80.124	-21.680	-44.187	101.196	.09233	-27.496
3.500	-24.000	39.510	-6.720	-92.420	78.074	-21.080	-44.738	99.682	.09088	-27.030
3.550	-25.430	39.050	-6.760	-90.901	76.103	-20.492	-45.293	98.103	.08953	-28.331
3.600	-26.190	38.360	-6.490	-89.473	74.206	-19.915	-45.850	96.675	.08823	-28.450
3.650	-26.460	38.240	-6.590	-88.131	72.379	-19.353	-46.409	95.316	.08699	-28.591
3.700	-26.030	40.190	-7.240	-86.871	70.617	-18.887	-46.970	94.025	.08582	-27.065

-.150 DT -36.340 DX 44.150 DY -44.991 DR 35.294 DD 347.5707 AZD

IDENTIFICATION	DT	DR	DD	ARD
1205740200	-.150	-44.991	35.294	-27.065
MEAN	-.150	-44.991	35.294	-27.065
SIGMA	0.000	0.000	0.000	0.000

Note: The observed velocity of the bomb was input as zero; consequently, the difference in velocity, VD, has the same magnitude as the computed velocity but opposite in sign.

APPENDIX E

UNSMOOTHED STORE POSITION DATA

T	X	Y	Z
.23	-4921.	1169.	5483.
.33	-4807.	1144.	5479.
.43	-4692.	1119.	5475.
.53	-4580.	1095.	5470.
.63	-4465.	1069.	5466.
.73	-4352.	1042.	5460.
.83	-4241.	1016.	5454.
.93	-4140.	993.	5449.
1.03	-4053.	973.	5444.
1.13	-3977.	955.	5439.
1.23	-3911.	941.	5436.
1.33	-3853.	929.	5430.
1.43	-3801.	925.	5427.
1.53	-3760.	914.	5423.
1.63	-3725.	907.	5419.
1.73	-3694.	903.	5415.
1.83	-3668.	899.	5413.
1.93	-3644.	895.	5409.
2.03	-3623.	890.	5406.
2.13	-3605.	884.	5402.
2.23	-3587.	882.	5399.
2.33	-3572.	878.	5395.
2.43	-3557.	876.	5392.
2.53	-3542.	877.	5388.
2.63	-3531.	874.	5385.
2.73	-3519.	872.	5381.
2.83	-3508.	870.	5377.
2.93	-3497.	868.	5373.
3.03	-3488.	866.	5369.
3.13	-3477.	866.	5365.
3.23	-3469.	867.	5360.
3.33	-3459.	867.	5355.
3.43	-3451.	864.	5350.
3.53	-3444.	865.	5345.
3.63	-3438.	860.	5341.
3.73	-3430.	862.	5335.

APPENDIX F

COMPUTED TRAJECTORY DATA

```
PROGRAM 033181002
    0 IJK
    0 JX     0 JY     0 JZ     0 JG     0 LFT     0 IEV

         J       IDR(1)     IDR(2)     IDR(3)          NUMBER AND INDICES OF CD VERSUS MACH NO TABLES READ FROM FILE
         0         0          0          0

 CD VERSUS TIME TABLES
     1 INDEX            8 NUMBER OF ELEMENTS IN TIME ARRAY
TIME     0.0000      .7500      .9000     1.0500     1.2000     1.3000     1.6000    20.0000
CD        .3994      .3994    40.0000    25.0000    60.0000    50.0000   100.0000   100.0000

                                    SANDIA B61
120574 200 DATE   37.830000 LATITUDE    0.000000 AZIMUTH  32.151500 GRAVITY   0 IR   0 KD   0 LV   0 LT   1 LC   0.000 TBO      1

     0.000 T  -5183.000 X   1223.900 Y   5493.700 Z   1147.000000 X*   -252.800000 Y*   -33.300000 Z*
     0.000 WAX     0.000 WAY       0. DRC        -.0050000000 CFY        -.0011000000 CFZ
  0.0 FF(1)  0.0 FF(2)  1.0 FF(3)  1.0 FF(4)  0.0 FF(5)  0.0 FF(6)  0.0 FF(7)  0.0 FF(8)  0.0 FF(9)  0.0 FF(10)

       T         ZSL         V       THRUST        CD        WX        WY       TEMP     DENSITY      SF         WT       DRIFT      AOF

     0.000 VG     0.000 ALE     0.000 WET     0.000 DIAM    0.0000 TD  0.000000 TS  1.000000 DR*   1 LLEND    1 ITH
  715.0000 WT   13.5406 DIA    0.0000 SC      .7500 TCH    0.0000 ZC   .150000 HT  1.000000 DS   0 IJ   4 IG   0 IT   2 ICH    0 LAST
  715.0000 WT   13.5406 DIA    0.0000 SC     1.3000 TCH    0.0000 ZC   .050000 HT  0.000000 DS   0 IJ   4 IG   0 IT   2 ICH    0 LAST
  715.0000 WT   13.5406 DIA    0.0000 SC     0.0000 TCH 5335.0000 ZC   .050000 HT  1.000000 DS   0 IJ   4 IG   0 IT   0 ICH    2 LAST

  715.0000 WT   13.5406 DIA    0.0000 SC      .7500 TCH    0.0000 ZC   .150000 HT  1.000000 DS   0 IJ   4 IG   0 IT   2 ICH    0 LAST
   0.00000  5494.380  1175.000    0.000     .39940   -10.038     .751   278.179  .0643677  0.000000   715.000    0.000     1.624
    .15000  5488.987  1171.373    0.000     .39940    -9.942     .408   278.207  .0643744  0.000000   715.000    0.000     1.860
    .30000  5482.891  1167.790    0.000     .39940    -9.834     .021   278.239  .0643819  0.000000   715.000    0.000     2.096
    .45000  5476.092  1164.250    0.000     .39940    -9.714    -.411   278.274  .0643903  0.000000   715.000    0.000     2.333
    .60000  5468.595  1160.753    0.000     .39940    -9.581    -.888   278.313  .0643995  0.000000   715.000    0.000     2.570
    .75000  5460.399  1157.299    0.000     .39940    -9.436   -1.409   278.355  .0644096  0.000000   715.000    0.000     2.809
  715.0000 WT   13.5406 DIA    0.0000 SC     1.3000 TCH    0.0000 ZC   .050000 HT  1.000000 DS   0 IJ   4 IG   0 IT   2 ICH    0 LAST
    .75000  5460.399  1157.299    0.000     .39940    -9.436   -1.409   278.355  .0644096  0.000000   715.000    0.000     2.809
    .80000  5457.529  1136.326    0.000   13.59960    -9.385   -1.591   278.370  .0644131  0.000000   715.000    0.000     2.869
    .85000  5454.679  1079.702    0.000   26.79980    -9.334   -1.772   278.385  .0644167  0.000000   715.000    0.000     2.973
    .90000  5451.931   997.408    0.000   40.00000    -9.286   -1.947   278.399  .0644200  0.000000   715.000    0.000     3.064
    .95000  5449.326   918.698    0.000   35.00000    -9.238   -2.117   278.413  .0644231  0.000000   715.000    0.000     3.162
   1.00000  5446.928   859.844    0.000   30.00000    -9.187   -2.294   278.429  .0644256  0.000000   715.000    0.000     3.266
   1.05000  5444.395   815.614    0.000   25.00000    -9.138   -2.466   278.444  .0644281  0.000000   715.000    0.000     3.380
   1.10000  5442.006   771.102    0.000   36.66667    -9.090   -2.635   278.459  .0644305  0.000000   715.000    0.000     3.497
   1.15000  5439.637   717.077    0.000   48.33333    -9.043   -2.799   278.473  .0644328  0.000000   715.000    0.000     3.624
   1.20000  5437.467   658.204    0.000   60.00000    -8.998   -2.956   278.487  .0644351  0.000000   715.000    0.000     3.761
   1.25000  5435.352   605.361    0.000   55.00000    -8.956   -3.105   278.500  .0644372  0.000000   715.000    0.000     3.911
   1.30000  5433.316   563.973    0.000   50.00000    -8.914   -3.249   278.512  .0644393  0.000000   715.000    0.000     4.072
  715.0000 WT   13.5406 DIA    0.0000 SC     0.0000 TCH 5335.0000 ZC   .050000 HT  1.000000 DS   0 IJ   4 IG   0 IT   0 ICH    2 LAST
   1.30000  5433.316   563.973    0.000   50.00000    -8.914   -3.249   278.512  .0644393  0.000000   715.000    0.000     4.072
   1.35000  5431.307   526.766    0.000   58.33333    -8.874   -3.391   278.525  .0644413  0.000000   715.000    0.000     4.359
   1.40000  5429.308   489.440    0.000   66.66667    -8.833   -3.533   278.537  .0644433  0.000000   715.000    0.000     4.651
   1.45000  5427.333   452.990    0.000   75.00000    -8.794   -3.672   278.549  .0644453  0.000000   715.000    0.000     4.951
   1.50000  5425.392   418.112    0.000   83.33333    -8.754   -3.810   278.561  .0644473  0.000000   715.000    0.000     5.261
   1.55000  5423.493   385.250    0.000   91.66667    -8.716   -3.944   278.573  .0644492  0.000000   715.000    0.000     5.583
   1.60000  5421.638   354.646    0.000  100.00000    -8.679   -4.075   278.584  .0644511  0.000000   715.000    0.000     5.919
   1.65000  5419.827   327.440    0.000  100.00000    -8.642   -4.203   278.596  .0644529  0.000000   715.000    0.000     6.271
   1.70000  5418.052   304.070    0.000  100.00000    -8.606   -4.329   278.606  .0644547  0.000000   715.000    0.000     6.640
   1.75000  5416.303   283.782    0.000  100.00000    -8.571   -4.452   278.617  .0644565  0.000000   715.000    0.000     7.026
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2.95000	5372.411	111.003	0.000	100.00000	-7.666	.168	278.083	.0646911	0.000000	715.000	0.000	21.969
3.00000	5370.320	108.528	0.000	100.00000	-7.622	.606	278.035	.0647077	0.000000	715.000	0.000	22.810
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3.20000	5361.679	100.019	0.000	100.00000	-7.442	2.414	277.836	.0647760	0.000000	715.000	0.000	26.302
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3.70000	5338.070	86.038	0.000	100.00000	-7.103	6.013	277.441	.0649093	0.000000	715.000	0.000	35.617
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3.75494	5335.299	84.980	0.000	100.00000	-7.081	6.282	277.411	.0649188	0.000000	715.000	0.000	36.663

0.000

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.750	-4329.60	1035.83	5459.92	1128.826	-248.749	-56.709	-23.851	5.295	-30.974	1166.205	1.06278	875.	1.23
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1000.000													

COMMAND-

APPENDIX G

GLOSSARY OF DATA-REDUCTION TERMS

GLOSSARY OF DATA-REDUCTION TERMS

ALTITUDE	altitude above mean sea level (ft)
AOF	angle of fall (deg)
ARC	arc length of trajectory (ft)
ARD	observed minus computed arc length (ft)
CD	aerodynamic drag coefficient (dimensionless)
CDS	product of the drag coefficient, CD, and the cross-sectional frontal area (ft^2)
DD	observed minus computed deflection at the terminal point (ft)
DENSITY	air density (lb/ft^3)
DR	observed minus computed range at the terminal point (ft)
DRIFT	drift of a projectile due to spin (ft)
DT	observed minus computed range at the terminal point (ft)
E*	component of wind blowing east (ft/sec)
G	total acceleration divided by the acceleration of gravity
MACH NO	Mach number
N*	component of wind blowing north (ft/sec)
SF	scale factor for aerodynamic drag
T	time from release (sec)
TEMP	air temperature (Kelvin)
THRUST	thrust of a rocket motor (lb)
V	velocity of a missile with respect to an earth fixed origin (ft/sec)
VA	true airspeed (ft/sec)
VD	observed minus computed velocity (ft/sec)
WT	weight of missile (lb)
WX	x component of wind (ft/sec)
WY	y component of wind (ft/sec)
X	x coordinate of position (ft)
X*	x component of velocity (ft/sec)

X**	x component of acceleration (ft/sec^2)
XD	observed minus computed x coordinate (ft)
Y	y coordinate of position (ft)
Y*	y component of acceleration (ft/sec)
Y**	y component of acceleration (ft/sec^2)
YD	observed minus computed y coordinate (ft)
Z	z coordinate of position (ft)
Z*	z component of velocity (ft/sec)
Z**	z component of acceleration (ft/sec^2)
ZD	observed minus computed z coordinate (ft)
ZSL	altitude above mean sea level (ft)

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Local:
E41
E431 (10)
G32 (Parry)
G40
G43
G44 (Abell)
K
K10
K11 (25)
K21
U13
U13D (Ludtke) (3)
U43E (Rosenberg)